

IV. "On the Difference of Potential produced by the Contact of different Substances." By R. B. CLIFTON, F.R.S., Professor of Experimental Philosophy in the University of Oxford. Received May 22, 1877.

In order fully to determine the origin of the difference of electric potential which is exhibited at the terminals of a voltaic element, and on which the electromotive force of the element depends, it is necessary to investigate the difference of potential produced at each contact of the different substances contained in the element.

This difference of potential was approximately determined by Volta in certain cases of contact of two metals, and the investigation of the electric condition of metals in contact has since been more fully studied by Kohlrausch and others.

The difference of potential arising when a metal and a liquid are brought in contact was pointed out by Volta, and has since been investigated by Becquerel, Péclet, Pfaff, Buff, Kohlrausch, and others; but the results obtained have in most cases merely shown that a difference of potential exists, and indicated the sign of this difference.

The methods of observation adopted by Becquerel, Péclet, and Pfaff do not indeed deal with the simple case of the contact of a given metal and a given liquid, but introduce more than one active contact; and the method of Buff, which Kohlrausch has also employed, is objectionable from the fact that, in addition to a metal-liquid contact a metal-glass or metal-lac contact has been introduced; and this latter contact is, I believe, far from inoperative, producing, indeed, a very considerable difference of potential.

In endeavouring to study this subject I have suppressed the solid dielectric and used a condenser having its opposed surfaces of metal and liquid separated by a plate of air, and have been careful to introduce only a single operative metal-liquid contact.

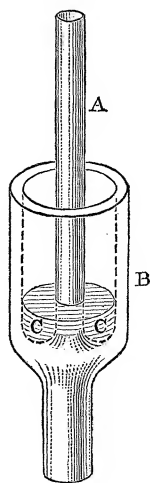
Although circumstances have prevented me from making much progress with quantitative measurements—and, indeed, the experiments have indicated that a change must be introduced into the apparatus employed before satisfactory measures of the difference of potential in certain important cases can be obtained, this difference being much less than previous investigations had led me to expect—yet I venture to lay before the Society a short account of some of the results obtained, and I hope at some future time to be able to communicate a more complete investigation with reliable quantitative determinations.

For the insulation of the apparatus, on which so much depends, I have employed a modification of the form of insulator suggested by Sir W. Thomson, which seems to me more convenient than the form in common use, while it equals, if it does not surpass, the latter in efficiency.

Fig. 1 represents one of these insulators, which consists of a glass

rod A, projecting from a glass cup B, to the bottom of which it is fused, so that the whole forms one piece of glass. Into the cup B a small

Fig. 1.



quantity of strong sulphuric acid (C) is introduced, which appears effectually to dry the inside of the cup and a portion of the glass rod. In many cases, during the time required for an observation, I failed to detect any loss of charge, although six of these supports are used in the apparatus. Even without sulphuric acid in the cup, this form of stand seems to insulate fairly well; for, even in very damp weather, the loss from six such stands rarely exceeded one per cent. of the charge in a minute.

The electrometer employed was Sir W. Thomson's quadrant electrometer, in the simple form constructed by the late Mr. Becker, which seems to me to be more sensitive than the more complex instrument, and to give equally reliable results, when it is required only to *compare* differences of potential. With this instrument and a condenser one thousandth part of the difference of potential produced by the contact of zinc and copper is very distinctly perceptible.

The condenser was furnished with horizontal plates, which could be separately levelled, and the upper plate could be moved normally to its surface, and adjusted with any required interval between the plates. In observations of the difference of potential between a metal and a liquid, the latter was contained in a glass vessel placed upon the lower plate, and connected with this plate by a strip or wire of the same metal as that covering the lower face of the upper plate.

A form of key was used by which the condenser-plates can be connected by a metallic circuit, while the four quadrants of the electrometer are maintained at the same potential, and the plates of the condenser can

then be connected with the respective terminals of the electrometer, the whole being well insulated. By the same key the alternate pairs of quadrants, in connexion with the respective plates of the condenser, can be charged to a definite difference of potential by a voltaic cell, and can then, while still in connexion with the condenser, be insulated without the least risk of introducing an unknown potential by touching the metallic portions of the apparatus by the hand.

With this apparatus the following experiments were performed.

The upper condenser-plate of copper was connected by an insulated copper wire with one terminal of the electrometer, the other terminal being connected by an insulated copper wire with the lower condenser-plate, which was again connected with a copper wire dipping in distilled water, contained in a vessel standing on the lower plate.

The two insulated wires connecting the condenser and electrometer were now brought into metallic connexion by the key, thus putting all four quadrants of the electrometer in connexion, and at the same time uniting the copper condenser-plate with the wire dipping in the water. The copper plate and the water thus become charged, the difference of potential being that due to the contact of copper and water.

The upper (copper) plate is next brought near the surface of the water, which acts as the lower plate of the condenser, the interval between the surfaces being from 0·1 millim. to 0·2 millim.

The metallic connexion between the connecting wires is now suppressed, and the upper condenser-plate quickly raised; the needle of the electrometer is at once deflected, and in the direction which indicates that the upper plate is *positive* with respect to the lower.

It appears, then, that when copper and distilled water are in contact they assume a difference of potential, copper being *positive* to distilled water.

Excepting Professor W. G. Hankel*, all previous observers, with whose results I am acquainted, agree in asserting that copper is *negative* to water; but I have repeated the above experiment a great number of times under varied conditions, and always with the same result, so that I feel confident that copper is really *positive* to water.

When the vessel on the lower plate contained a saturated solution of copper sulphate, and similar operations were performed to those above described, the result was that copper and a saturated solution of copper

* Abhandl. d. königl. sächs. Gesellschaft der Wissenschaften, vol. xi. p. 605.

My experiments gave no indication of the change of sign of the potential of copper with respect to that of water, which, according to Professor Hankel, takes place during the first few minutes of contact. It is possible, however, that this change may have taken place, although the copper wire had not been immersed more than two or three minutes when the difference of potential was observed.

At the time my experiments were performed I had not seen Professor Hankel's paper.

sulphate assume in contact a difference of potential, copper being *positive* to the solution of copper sulphate.

The difference of potential in this case appears to be about $\frac{3}{10}$ of the difference of potential of copper and water in contact ; but I do not yet feel in a position to make any very definite statements with respect to the relative magnitudes of the differences of potential of metals and liquids in contact.

When the liquid employed was commercial sulphuric acid diluted with twenty times its volume of distilled water, the difference of potential observed was very small, so small, indeed, that copper and this dilute acid in contact may be regarded as practically at the same potential ; a very small difference of potential, however, exists in this case, and copper is *negative* to this dilute acid.

Copper and a strong aqueous solution of caustic potash assume in contact a small difference of potential, larger, however, than that observed in the last case, and copper is *negative* to the solution of caustic potash.

There is a very marked difference of potential between copper and an aqueous solution of potassium sulphide (liver of sulphur) in contact, copper being *negative* to this solution.

Between copper and a strong aqueous solution of potassium cyanide in contact there is a very considerable difference of potential, copper being *negative* to the solution. The difference of potential in this case is comparable with the difference observed when zinc and copper are in contact.

Similar experiments were performed with the upper condenser-plate of well-cleaned zinc, the liquid being connected with the lower plate by a strip of zinc. When the liquid is distilled water there is a marked difference of potential, zinc being *positive* to water ; and the magnitude of this difference of potential appears to be, very approximately at least, the same as that observed in the case of copper and water.

With zinc and dilute sulphuric acid the difference of potential is extremely small ; but zinc is slightly *negative* to the dilute acid (1 volume of sulphuric acid in 20 volumes of distilled water).

In experimenting with zinc the greatest care is necessary in cleaning the surface of the zinc condenser-plate, as zinc oxide is strongly negative to zinc ; when the plate is very slightly tarnished, the sign of the difference of potential exhibited by the condenser, in the case of water, is reversed, the oxidized zinc being *negative* to distilled water.

When the upper condenser-plate was of iron, and distilled water acted as the lower plate, there was a small but distinct difference of potential, iron being *negative* to water.

The experiments above described seem to indicate that zinc and copper are about equally positive to water, and that consequently zinc and copper dipping in water are nearly at the same potential.

This conclusion has been also arrived at by Sir W. Thomson as the

result of an experiment described by Professor F. Jenkin in his 'Text Book of Electricity and Magnetism;' but this experiment seems to leave something to be desired on the score of sensitiveness, and I was anxious to put the conclusion to a somewhat severer test. With this object the following experiment was performed:—

The condenser was furnished with carefully cleaned plates of zinc and copper, which were connected as before by insulated copper wires with the respective terminals of the electrometer. Into a vessel containing distilled water two insulated plates of zinc and copper respectively (both carefully cleaned) were plunged and connected with the key above mentioned by copper wires. By means of this key the zinc plate in water was connected with the zinc condenser-plate, and the copper plate in water with the copper condenser-plate, the two condenser-plates being separated by an interval certainly not more than 0.2 millim. The needle of the electrometer was at once deflected, and in a few minutes became stationary in a position showing a considerable deflection due to the difference of potential of the terminals of the zinc-water-copper element, while the zinc and copper plates of the condenser are necessarily at the same potentials as the zinc and copper plates in the water.

The key was now opened, so that the condenser-plates and electrometer, still in connexion as before, became insulated, and no change in the deflection of the electrometer-needle was perceptible.

The condenser-plates were now quickly separated, but the electrometer-needle remained absolutely undisturbed. It appears, then, that the zinc and copper plates in water are so nearly at the same potential, that the apparatus employed fails to show the difference between their potentials. Considering that if the zinc and copper condenser-plates are connected by a wire when at the same distance apart, and are then insulated and separated in the same way, the needle is so strongly deflected as to be turned completely round, I feel justified in stating that clean zinc and copper plates when first plunged in distilled water, if not absolutely at the same potential, certainly do not differ in potential by the thousandth part of the difference of potential produced by the contact of zinc and copper.

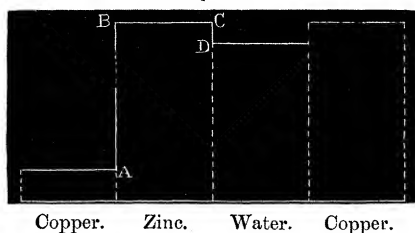
The electromotive force, then, of a voltaic element composed of zinc and copper plates dipping in distilled water, and connected by a copper wire, is at first, for all practical purposes, due entirely to the difference of potential produced by the contact of zinc and copper, the water having no perceptible effect.

This was assumed by Volta, on less conclusive evidence, and forms the basis of his reasoning with respect to the action of the pile devised by him.

I cannot, however, agree with Professor Jenkin that the water is also at the same potential as the zinc and copper plates immersed in it. The above-mentioned experiments seem to me to show that the water is negative to both plates, but to the same extent.

If the potentials of the different substances in the voltaic element just mentioned be represented by lines drawn perpendicular to an axis along which the substances are distributed in the order in which they occur in the element, the zinc being furnished with a copper terminal, the distribution of potential, when the circuit is not completed, is represented by fig. 2.

Fig. 2.

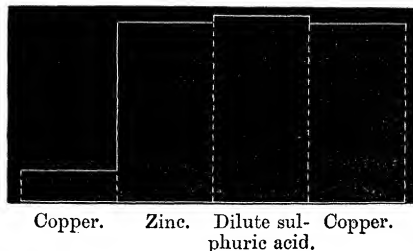


As I have not yet obtained sufficiently trustworthy measures of the difference of potential between zinc or copper and liquids, this figure and those which follow do not represent *quantitative* relations; the zinc-water difference of potential C D may possibly be represented as too large, compared with the zinc-copper difference of potential A B. The figures are merely intended to represent the *distribution* of the potentials.

Similar experiments were performed with zinc and copper plates dipping in dilute sulphuric acid (1 volume of acid in 20 volumes of distilled water), and with the same result, viz. that the zinc and copper plates are, as far as can be observed, at the same potential; and in this case, as the experiments previously described show, the liquid is very nearly at the same potential as the immersed metals.

It is possible that with more dilute sulphuric acid Professor Jenkin's statement will be found to be absolutely true, the zinc, copper, and dilute acid in which they are immersed being all at the same potential; but with the dilute acid used the distribution of potential in this voltaic element is represented, in the same manner as before, by fig. 3.

Fig. 3.



The series of metals and liquids which I have examined is small; but,

so far as it extends, the phenomenon of two metals being at the same potential when immersed in a liquid is peculiar to zinc and copper, and only takes place in the case of these metals when the liquid is either water or dilute sulphuric acid, and when the metals have been recently placed in it.

For instance, when zinc and copper are immersed in a solution of caustic potash, there is a small but distinct difference of potential between the zinc and copper, copper being positive to zinc. Again, iron and copper in distilled water exhibit a marked difference of potential, the copper plate being positive to the iron plate; this is, of course, a necessary consequence of the fact, previously stated, that copper is positive to water, while iron is negative to water, and it is confirmed by the experiments with a copper-water-iron element.

Similar observations were made with zinc and iron in distilled water, with the result that zinc in water is positive to iron in water.

Connected with the experiment by which I have attempted to show that well-cleaned zinc and copper in water are at the same potential, there are some points which seem worthy of mention. When the condenser-plate of zinc is thoroughly cleaned, but the zinc plate in the water is not cleaned with the same care, the copper plate at first appears to be slightly *negative* to the zinc plate; but after a short time (the immersion of the plates being continued) this difference of potential disappears, and the two plates are, as before mentioned, exactly at the same potential. If the plates continue immersed a small difference of potential again appears between them; but now the copper appears to be *positive* to the zinc, and this difference of potential slowly increases until it attains, after some hours, a considerable magnitude.

A possible explanation of these changes seems to be that at first the zinc oxide has not been entirely removed, and, being strongly negative to the zinc, it causes the copper to appear negative to the zinc; but as the zinc becomes acted upon by the water*, its surface becomes, partially at least, coated with hydrogen, which is positive to zinc, and hence the copper plate, assuming the same potential, or nearly so, as the altered zinc surface, becomes positive to the zinc plate. As the time of immersion is prolonged the coating of hydrogen on the zinc becomes more complete, and the apparent positive potential of the copper with respect to the zinc increases, the zinc plate becoming less and less operative in the water, and serving more and more as a mere support for the hydrogen.

With amalgamated zinc the coating of hydrogen is formed much more evenly and rapidly; and thus, in spite of the presence on the zinc plate of the mercury, which is considerably *negative* to copper, an amalgamated zinc plate and a copper plate in water, or in dilute sulphuric acid, exhibit, when first immersed, a larger difference of potential than zinc and copper

* The zinc used in these experiments was commercial, not pure zinc.

under the same circumstances. The result of my experiments up to the present has, however, led me to conclude that the final difference of potential between amalgamated zinc and copper in water, or dilute sulphuric acid, is very nearly, if not exactly, the same as that exhibited by zinc and copper under the same conditions, if the immersion of the plates is sufficiently prolonged.

This rise of the difference of potential between the plates of a voltaic element while the circuit is open seems to me to be due to exactly the same cause as the so-called polarization of the plates when the circuit is closed, but operating in the opposite direction.

The natural result of this change in the difference of potential of the immersed plates is, that, in a cell composed of zinc and copper plates immersed in water, the zinc being furnished with a copper terminal, the difference of potential exhibited by the terminals should increase with the length of time the plates have been immersed, the circuit of course never having been completed. In order to verify this I have endeavoured to compare, by the electrometer, the difference of potential of the terminals of such a cell with the difference of potential of the terminals of a Daniell's cell. Several determinations gave nearly the same results; and the following numbers show the magnitude of the change which takes place:—

D represents the difference of potential of a Daniell's cell, in which the amalgamated zinc plate is immersed in a liquid composed of 1 part by weight of pure sulphuric acid and 4 parts by weight of distilled water. According to Mr. Latimer Clark, $D = 1.079$ volt.

The difference of potential of the copper terminals of a zinc-water-copper cell is,

immediately after the immersion of the plates,

0.760 D, or 0.820 volt ;

after the plates have been immersed 1.5 hour,

0.821 D, or 0.886 volt ;

after the plates have been immersed 3 hours,

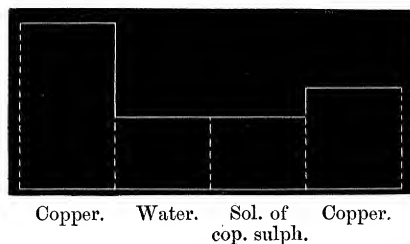
0.838 D, or 0.905 volt.

The experiments with the condenser above mentioned, by which the corresponding change in the potentials of the plates themselves was observed, would indicate that the difference of potential of zinc and copper in contact (which I will represent, as usual, by $\text{Zn} \mid \text{Cu}$) is between 0.760 D and 0.821 D, and nearer to the former. This indication is justified by the result of direct experiment, as described in a later part of this paper.

From the observations previously described as to the difference of potential of copper with respect to water and with respect to a solution of copper sulphate, it follows that when copper plates are immersed

respectively in water and in a saturated aqueous solution of copper sulphate, the two liquids being separated by a porous partition, if no difference of potential arise between the liquids in contact, the copper plate in water will be *positive* to the copper plate in the copper-sulphate solution. The distribution of potential will be indicated by fig. 4.

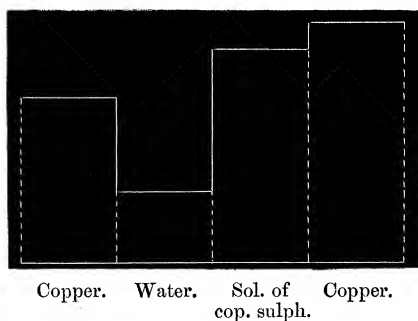
Fig. 4.



Experiment, however, shows that the copper plate in water is distinctly *negative* to the copper plate in the copper-sulphate solution. Hence it follows that there is a considerable difference of potential between these two liquids in contact, the copper-sulphate solution being positive to distilled water.

The real distribution of potential in this case is therefore represented in fig. 5; as before, these figures are not drawn to scale, but only represent qualitatively the distribution of potential.

Fig. 5.



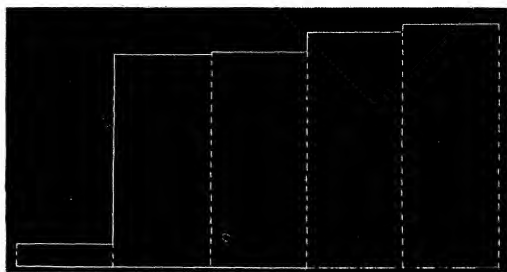
Similar experiments indicate (though, in the absence of perfectly reliable measures, perhaps not so conclusively) that a saturated solution of copper sulphate is positive to dilute sulphuric acid and also to a solution of potassium cyanide when the first liquid is in contact with either of the two latter.

Indeed the experiments I have performed lead me to conclude that the 11 to 13 per cent., by which the difference of potential exhibited by the copper terminals of a Daniell's cell exceeds the difference of potential,

shown by the copper terminals of a cell composed of amalgamated zinc and copper in dilute sulphuric acid is mainly due to the contact of the dilute sulphuric acid and the solution of copper sulphate in the Daniell's cell. The contact between the copper and the copper-sulphate solution appears to add but little, and the contact of the zinc and dilute acid next to nothing, to the difference of potential; at all events in the case where the acid solution is weak.

In such a Daniell's cell the distribution of potential appears to be that indicated in fig. 6.

Fig. 6.



Copper. Amalgama- Dilute Sol. of Copper.
ted zinc. sulph. acid. cop. sulph.

The very large difference of potential between copper and a solution of potassium cyanide in contact, to which attention has been called at the commencement of this paper, coupled with the fact that this difference is of the opposite sign to that exhibited by copper and water, or copper and a solution of copper sulphate in contact, shows that a voltaic cell of considerable power may be constructed containing only one metal and two liquids. Such cells have long been known; for instance, Becquerel's cell, composed of platinum in nitric acid, and platinum in a solution of caustic potash; but the only cell of this kind which I have seen described, in which copper is the only metal present, is that devised by the late Emperor Napoleon.

A cell composed of copper in water and copper in a solution of potassium cyanide (1 part by weight of cyanide to 5 parts by weight of distilled water) shows a difference of potential between its terminals equal to 0.923 D, or 0.996 volt.

This cell has, of course, a very large internal resistance; but this resistance may be greatly diminished by substituting a saturated solution of copper sulphate for the water; and although this substitution causes a loss of potential at the junction of the copper and liquid, yet it is much more than compensated by the gain at the junction of the two liquids.

Thus a cell composed of copper in a saturated solution of copper sulphate, and copper in a solution of potassium cyanide (1 part by weight of

the cyanide to 5 parts by weight of distilled water), exhibits at its terminals a difference of potential equal to 1.102 D, or 1.189 volt.

In order to test the constancy of this last-mentioned cell, it was constructed in the form usually adopted for Grove's battery: the inner porous vessel contained 60 cub. centims. of the potassium-cyanide solution, and in it was inserted a plate of copper; the outer vessel contained a solution of copper sulphate maintained in a state of saturation by the presence of crystals of the salt, and the copper plate in this vessel was bent round the flat porous vessel so as nearly to touch it on both sides. The terminals were now connected by short wires with a tangent galvanometer, and the current allowed to pass uninterruptedly, with the following results:—

	Deflection of the needle.
At the time the circuit was closed	34
After 6 minutes	58
„ 15 „	73
„ 22 „	75
„ 30 „	75
„ 45 „	68.5
„ 62 „	46
„ 75 „	28
„ 90 „	25
„ 105 „	23.5
„ 120 „	21.5

It appears, therefore, that though, for a voltaic element containing only one metal, this cell has a considerable electromotive force, it is far from constant in its action.

In endeavouring to compare the differences of potential arising in pairs of metals in contact, I have employed the method of Kohlrausch (Wiedemann's 'Galvanismus,' 1861, vol. i. p. 28), in which, by the aid of a condenser having its plates of two metals, the difference of potential of these metals, due to their contact, is compared with the difference of potential exhibited by the terminals of a constant voltaic element.

For the purpose of comparison I used a Clark's standard cell (Phil. Trans. vol. clxiv. p. 1), relying upon the reported constancy of the difference of potential of its terminals; and although I find that this difference is very far from constant, yet the rate of change is slow, and for experiments performed at intervals of only a few days it may be considered constant within the limits of the experimental errors to which my present apparatus seems liable.

I will denote by C the difference of potential of the terminals of this cell at the time the following measures were made:—

With condenser-plates of iron and copper carefully cleaned I obtained

$$\begin{array}{r} \text{Fe} \mid \text{Cu} = 0.0774 \text{ C.} \\ 0.0717 \text{ C.} \\ \hline 0.0745 \text{ C. (Mean.)} \end{array}$$

With condenser-plates of zinc and copper carefully cleaned immediately before commencing the series of measurements the following results were obtained :—

$$\begin{array}{r} \text{Zn} \mid \text{Cu} = 0.6180 \text{ C.} \\ 0.6238 \text{ C.} \\ 0.6172 \text{ C.} \\ 0.6204 \text{ C.} \\ \hline 0.6198 \text{ C. (Mean.)} \end{array}$$

In these experiments the circumstances were altered as much as possible, the condenser-plates were adjusted at different intervals, and the plates were in some cases separated slowly, and in others as rapidly as possible ; yet the greatest amount of variation in the measures obtained scarcely exceeds one per cent.

These two measurements lead, by Volta's law, to

$$\text{Zn} \mid \text{Fe} = 0.5453 \text{ C.}$$

Direct experiments with condenser-plates of zinc and iron gave the following results :—

$$\begin{array}{r} \text{Zn} \mid \text{Fe} = 0.5228 \text{ C.} \\ 0.5329 \text{ C.} \\ 0.5198 \text{ C.} \\ \hline 0.5251 \text{ C. (Mean.)} \end{array}$$

Unfortunately in these experiments the plates were not cleaned immediately before the measurements were made, and the zinc plate was very slightly oxidized, so that this series must give a value for Zn | Fe below the true value. For this reason more confidence is to be placed in the result deduced from the experiments with Zn and Cu and with Fe and Cu than in that obtained by the last series.

When mercury acted as the lower plate of the condenser and the upper plate was of iron, I obtained

$$\text{Fe} \mid \text{Hg} = 0.23144 \text{ C.}$$

The above-mentioned results lead, then, to the following :—

$$\begin{array}{l} \text{Fe} \mid \text{Cu} = 0.120 \text{ . Zn} \mid \text{Cu.} \\ \text{Zn} \mid \text{Fe} = 0.880 \text{ . Zn} \mid \text{Cu.} \\ \text{Fe} \mid \text{Hg} = 0.373 \text{ . Zn} \mid \text{Cu.} \\ \text{Zn} \mid \text{Hg} = 1.253 \text{ . Zn} \mid \text{Cu.} \\ \text{Cu} \mid \text{Hg} = 0.253 \text{ . Zn} \mid \text{Cu.} \end{array}$$

Comparison of the difference of potential of zinc and copper in contact with that of the terminals of the standard Daniell's cell before mentioned gave

$$\text{Zn} \mid \text{Cu} = 0.7892 \text{ D};$$

or, assuming Mr. Latimer Clark's measurement of D, viz. 1.079 volt,

$$\text{Zn} \mid \text{Cu} = 0.8516 \text{ volt.}$$

This value shows that, on the occasion of the previous measures,

$$C = 1.273 \text{ D} = 1.374 \text{ volt.}$$

By using this value of Zn | Cu in the preceding results, the values contained in the following Table are obtained :—

	D.	Volt.
Zn Fe	0.694	0.749
Fe Cu	0.095	0.102
Cu Hg	0.200	0.216
Zn Cu	0.789	0.852
Fe Hg	0.295	0.318
Zn Hg	0.989	1.067

The experiments from which the above-mentioned ratios of Zn | Cu to the difference of potential of the terminals of Clark's standard cell are deduced were performed on January 5 and January 8, 1877. A series of similar experiments had been previously made on December 15 and December 16, 1876, which led to the following results, C' representing the difference of potential of the terminals of Clark's cell at that time :—

$$\text{Zn} \mid \text{Cu} = 0.5863 \text{ C'.$$

$$0.5842 \text{ C'.$$

$$0.5912 \text{ C'.$$

$$0.5890 \text{ C'.$$

$$0.5877 \text{ C'. (Mean.)}$$

Hence, since Zn | Cu = 0.7892 D = 0.8516 volt,

$$C' = 1.343 \text{ D} = 1.449 \text{ volts.}$$

On March 13 and 15, 1877, Clark's cell was directly compared with a Daniell's cell, giving

$$\begin{array}{r} C'' = 1.192 \text{ D.} \\ 1.178 \text{ D.} \\ \hline 1.185 \text{ D. (Mean.)} \end{array}$$

On March 28, 1877, the same comparison was repeated, leading to the result

$$C''' = 1.169 \text{ D.}$$

Hence it appears that the difference of potential exhibited by the terminals of Clark's standard cell is constantly diminishing during the period of these experiments, being

	Standard Daniell.	Volt.
On December 15-16, 1876.....	1.343	1.449
„ January 5-8, 1877	1.273	1.374
„ March 13-15, 1877	1.185	1.279
„ March 28, 1877	1.169	1.262

In the course of my experiments I have had occasion to compare the difference of potential exhibited by the copper terminals of various voltaic elements with the difference of potential of the terminals of a standard Daniell's cell, in which the amalgamated zinc plate is immersed in a liquid composed of 1 part by weight of pure sulphuric acid and 4 parts by weight of distilled water. Some of the results have been already mentioned, and the whole are contained in the Table accompanying this paper, arranged with the differences of potential in ascending order of magnitude.

In all the cells referred to in this Table the terminals have been carefully insulated, so that in no case has a current circulated in any of the cells; the difference of potential observed is therefore free, or nearly free, from the influence of the phenomenon known as the polarization of the metal plates.

I hope shortly, with somewhat improved apparatus, to undertake a more extended series of measurements of the differences of potential due to the contact of metals, and metals and liquids, and by using purer metals to be able to present to the Society results of more value than those contained in the present paper.

TABLE showing the Difference of Potential of the Copper Terminals of Voltaic Elements in which no Current has circulated.

Composition of Element.	Difference of Potential in terms of	
	Standard Daniell.	Volt.
Tin in dilute sulphuric acid (1 volume of acid to 8 volumes of distilled water) and Tin in solution of caustic potash (1 part by weight of caustic potash to 5 parts by weight of distilled water)	0·532	0·574
Tin in distilled water and Tin in solution of caustic potash (1 part by weight of caustic potash to 5 parts by weight of distilled water)	0·713	0·769
Copper and zinc (both well cleaned) in distilled water :— When metals are first immersed	0·760	0·820
After immersion for 1·5 hour	0·821	0·886
" " " 3 hours	0·838	0·905
Copper and amalgamated zinc in dilute sulphuric acid (1 volume of commercial sulphuric acid to 8 volumes of distilled water)	0·856	0·924
Copper in distilled water and Copper in solution of potassium cyanide (1 part by weight of potassium cyanide to 5 parts by weight of distilled water)	0·923	0·996
Daniell :— Copper in saturated solution of copper sulphate and amalgamated zinc in dilute sulphuric acid (1 volume of commercial sulphuric acid to 10 volumes of distilled water)	0·958	1·034
Daniell :— Copper in saturated solution of copper sulphate and amalgamated zinc in dilute sulphuric acid (1 volume of commercial sulphuric acid to 8 volumes of distilled water)	0·982	1·059
Carbon and zinc in a saturated aqueous solution of potassium bichromate	0·996	1·074

TABLE (continued).

Composition of Elements.	Difference of Potential in terms of	
	Standard Daniell.	Volt.
Copper in saturated solution of copper sulphate and copper in solution of potassium cyanide (1 part by weight of potassium cyanide and 5 parts by weight of distilled water)	1·102	1·189
Smee :— Platinized silver and amalgamated zinc in dilute sulphuric acid (1 volume of commercial sulphuric acid to 8 volumes of distilled water) . .	1·193	1·288
Leclanche :— Solution of ammonium chloride in distilled water	1·268	1·369
Grove :— Platinum in commercial nitric acid (sp. gr. 1·36) and amalgamated zinc in dilute sulphuric acid (1 volume of commercial sulphuric acid to 12 volumes of distilled water)	1·504	1·622
Platinum in acid solution of potassium bichromate (4 volumes of saturated aqueous solution of potassium bichromate to 1 volume of commercial sulphuric acid) and Amalgamated zinc in dilute sulphuric acid (1 volume of commercial sulphuric acid to 8 volumes of distilled water)	1·678	1·811
Carbon and zinc in acid solution of potassium bichromate (4 volumes of saturated aqueous solution of potassium bichromate to 1 volume of commercial sulphuric acid)	1·701	1·835

V. "The Physiology of Sugar in relation to the Blood."
By F. W. PAVY, M.D., F.R.S. Received June 12, 1877.

In a communication published in the 'Transactions of the Royal Society' (1860, p. 579) I gave the results of analyses showing that what had previously been looked upon, under Bernard's glycogenic theory, as the natural condition of the blood in relation to sugar was a fallacious representation due to a *post mortem* change being allowed to exert its in-

Fig. 2.



Copper.

Zinc.

Water.

Copper.

Fig. 3.



Copper.

Zinc.

Dilute sul-
phuric acid.

Copper.

Fig. 4.



Copper.

Water.

Sol. of
cop. sulph.

Copper.

Fig. 5.



Copper.

Water.

Sol. of
cop. sulph.

Copper.

Fig. 6.



Copper. Amalgama- Dilute Sol. of Copper.
ted zinc. sulph. acid. cop. sulph.